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Determination of a Critical Angle (θ_C) for Track Revelation for Different CR-39 Nuclear Track Detector Materials.

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Abstract

Different thicknesses of 50 samples of commercially CR-39 Solid State Nuclear Track Detectors (SSNTDs) have been prepared with different ages and from different produced companies. Track parameters and plotting profiles, using computer program TRACK_TEST ware calculated. Detector efficiency has been found to be depends strongly on the critical angle for track revelation (θ_C). On the other hand, critical angle depends strongly on the bulk etch rate.The results were specified that the detectors older than 3 years seemed to show odd behaviors of V_B with detector efficiency. For age=3years the efficiency decreases exponentially for different alpha particle energy, and the bulk etch rate (V_B) increases with decreasing age. This behavior may be important in applications of this detector; for example, the calibration factor for radon measurements should be established by taking into account the age of the detector

Keywords: CR-39 detectors, TRACK_TEST program, Critical angle and Detector efficiency

1-Introduction

The science of solid-state nuclear track detectors (SSNTDs) was born in 1958 when D.A. Young discovered the first tracks in a crystal of LiF [1]. The etch pits, later called ‘‘tracks’’, were found in a LiF crystal which was previously placed in contact with a uranium foil, irradiated with slow neutrons and treated with a chemically aggressive solution. The damaged regions constituted more chemically active zones than the surrounding undamaged areas.

Operation of the (SSNTD) is based on the fact that a heavy charged particle will cause extensive ionization of the material when it passes through a medium. A recent review on SSNTDs has been given in reference [2] while a review of using of SSNTDs in cellular radiation biology can be found in [3].

One of the most commonly used nuclear track detectors is the CR-39 detector and because of its good sensitivity, stability against various environmental factors and high degree of optical clarity, CR-39 has become the state of the art etched track detector for environmental radon [4-6]. And it has been commonly used as (SSNTDs) in which visible tracks can be formed after ion irradiation and suitable chemical etching [5].

A heavy charged particle leads to intensive ionization when it passes through matter. Along the path of the particle, a zone called the latent track is created which is enriched with free chemical radicals and other chemical species.

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If a piece of material containing the latent track is exposed to some chemically aggressive solution (such as NaOH or KOH solution), the chemical reaction would be more intensive in the latent track.

Such a solution is called the etchant. Through the etching, the latent track becomes visible as a particle "track" which may be seen under an optical microscope.

Ion-track growth in SSNTDs has been suggested to base on two parameters, V_T and V_B ,where V_T is the track etch rate (i.e., the rate of chemical etching along the ion trajectory) and V_B is the bulk etch rate (i.e., the rate of chemical etching of the undamaged surface). The track etching velocity V_T along the trajectory of the charged particle in the given detector media is the function of the charged particle type and energy, and the quantities V_B is dependent on temperature and etchant concentration .The tracks were considered as three-dimensional objects [7], which enabled calculations of the track parameters including the lengths of the major and minor axes of track openings, and plotting of their profiles [8, 9]. The generation of visible etched tracks by charged particles is only possible if the angle of incidence is lower than a critical angle θ_c. This quantity has been calculated from the bulk etch rate and the track etch rate varying along the particle trajectory [10].

In order to study the suitability of CR-39 for applying, various track registration parameters, such critical angle of etching and registration efficiency are of immense importance.

In the present work, we describe our efforts to determine the most important track registration parameters, i.e. critical angle of etching, the effect of storage (aging) on track registration property of CR-39 and etching efficiencies for application by using TRACK_TEST computer program [11].

2-TRAC_TEST Program Summery

A computer program called TRACK_TEST for calculating parameters (lengths of the major and minor axes) and plotting profiles in nuclear track materials described by Nikezica [11]. The programming steps are outlined, including calculations of alpha-particle ranges, determination of the distance along the particle trajectory penetrated by the chemical etchant (Track depth), calculations of track coordinates, determination of the lengths of the major and minor axes and determination of the contour of the track opening resulted from light-ion irradiation and subsequent chemical etching was described in reference [12]

Based on the programming steps described above, a computer program was written in the standard Fortran 90 language. The program integrates routines for calculating of the coordinates of the track profile, the contour of the tack opening and for graphical presentation. Besides the detector type, the input data include the alpha-particle energy, incident angle, and the V_T functions and V_B.

3-The Track Registration and the Critical Angle

Nuclear tracks formed by heavy ions are very small (only some tens of nm in diameter). Fortunately, any of the nuclear track detectors has an appropriate etchant, the basic characteristics of which are that the track etching velocity V_T along the trajectory of the ions is larger than the bulk etching velocity V_B for the etchant used under given etching conditions.

Figure 1 shows the track geometry in nuclear track detectors for particles at normal incidence at constant V_T, the basic quantities are the base cone diameter, major and minor axes, the cone height of the etched track, the bulk etch rate V_B and the track-etch rate V_T.

The cross-section of the post-etch surface and the cone is a circle with a diameter D, i.e., the radius of the track opening. For the sake of simplicity, the problem can be considered in two dimensions as shown in Fig. 1.

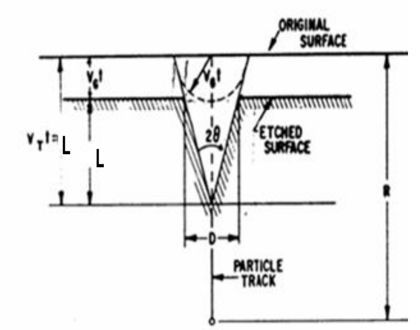

Fig.1: Track geometry for normal incident particles [2]

The track depth is given by:

$L= (V_T-V_B)$ t…………………….………..(1)

where t is the etching time , and from Fig.1 , we conclude see that :V_B=h/t ………..(2)

Where h is the thickness removed layer which can be measured by using digital micrometer.

From Eq.1 and 2, V can be found as:

V=1+L/h ……………………….…………..(3)

Track development is governed by the ratio V= V_T/V_B and track formation is not possible if V is smaller than or equal to 1. In other words, the condition V > 1 must be fulfilled to form a track [3].

The critical angle θ_c is an important factor for track registration and for investigation of detector efficiency, and it is given by the following equation

$\theta_c = \mathrm{Sin}^{-1}(1/V)$…………………(4)

The measurements of track depth were taken form the out put data of the program (TRACK_TEST).

The generation of visible etched tracks by charged particles is only possible if the angle of incidence is greater than critical angle θ_c. This quantity has been calculated from the track diameter and the track depth equation [4];

If the angle of incidence θ, of the particle is lower than critical angle of etching θc then the CR-39 track detector is not able to record the track.

The track registration efficiency *f* of nuclear track detectors strongly depends on the critical angle and more details about critical angle with track registration has been given in reference [13] and it is defined as;

f=1- sinθc…………………………….(6)

In an application of CR-39 is to radon monitoring or neutron dosimetry, the number of etch pits is important. Therefore, constancy of detection efficiency of CR-39 is a key factor determining the reliability of the measured results in these applications.

4- Materials and Methods

4.1 Materials of the Experiments

4.1.1 CR-39 Nuclear Track Detectors

The CR-39 plastic track detector is a $C_{12}H_{18}O_7$ polymer with density 1.3 g/cm^{3}and it is stands for Columbia Resin [13]. The CR-39 detectors used in the present study were collected from seven different companies and the detectors were different in producing date. The main characteristics of the detectors are listing in Table 1.

4.1.2 Irradiation Systems

The radioactive source of ^{226}Ra with 5.49MeV was used for the irradiation of alpha particle. For controlling the final alpha energies incident on the detector (from 1 to 5 MeV), the distance between the radium source and the detector surface, has been adjusted.

residual energy can be calculated using the follow equation [14].

$$E_a(X) = E_a(0)\left(1 - \frac{X}{R}\right)^{\frac{2}{3}} ------(7)$$

Where $E_a(0)$: is (=5.49 MeV) the energy of alpha source,

X: are the source-detector distances in air at normal temperature and pressure (NTP),

R: is the alpha particle range in the air (= 4.08 cm)

Table (1): Main characteristics for the different CR-39 Detectors

Density (gm/cm^3)	**Company**	**Thickness (µm)**	**Chemical composition**	**Reflection**	**Refractive index**
1.31	Fukuvi Chemical Industry, (Japan)	95 and 100	$C_{12}H_{18}O_7$ polymer	7.7%	1.495
1.31	Mouldings (Pershore) Limited Worcestershire , England	101, 100, 99and 98	$C_{12}H_{18}O_7$ polymer	7.7%	1.495
1.31	American Acrylic and Plastics Inc.	108	$C_{12}H_{18}O_7$ polymer	7.7%	1.495
1.31	Radaulab Norway	128	$C_{12}H_{18}O_7$ polymer	7.7%	1.495
1.31	Russian	111	$C_{12}H_{18}O_7$ polymer	7.7%	1.495
1.31	Intercast Europe (Parma, Italy)	100	$C_{12}H_{18}O_7$ polymer	7.7%	1.504

In this geometry (See Fig.2) a slot of radius (1.5) mm was centred in the upper disc, above which the alpha radioactive – source is fixed .In the lower disc a slot of same radius was centred, where the detector foils are mounted for irradiation, the distance between the two discs can be varied to get different alpha energies. Various tubes of 1.5mm in diameter between these two discs were used to collimate the alpha particles. Thus, the range of alpha particle in air throughout the tubes was changed from a maximum value down to a minimum value by varying the source detector distance. The

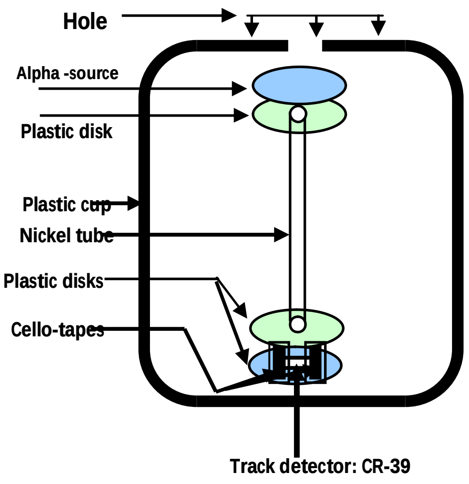

Fig.2Schematic diagram of the experimental arrangement used to irradiate CR-39[14].

4.1.3 Etching Method

The sodium hydroxide aqueous solution (NaOH) of 6 mol per liter was used as the etching solution. The etching was done in a bottle with a tight lid to prevent change in the concentration of the etching solution due to vaporization of water and absorption of moisture. A water bath was used for heating the etching solution at 70 C^o with the precision of ± 0.1C^o for 4.5hours [14].

4.1.4 Measurement of the Track Depth

Measurements of track depth were taken form the out put data of the TRACK_TEST program, via coordinates of the track profile and the contour of the tack opening.

4.1.5 Change of the Bulk Etch Rate

The standard determination of V_B is based on the measurement of the thickness of the detector after etching times. The thickness is measured with a digital micrometer of 1μm accuracy in 10 positions on the detector foil. The average bulk etch velocity is ($V_B = \Delta h/2\Delta t$), where Δh is the mean thickness difference after a Δt etching time. Since V_B is one of the most important parameters that control the formation and development of tracks, there have been a large number of literatures discussing V_B. Here, an incomplete survey of works on V_B is given. It has been shown that V_B depends on many factors like the purity of the basic substances, the molecular structures of polymers, conditions of polymerization, environmental conditions during the irradiation and finally on etching conditions [15].

4.2 Description of Experimental Procedure

4.2.1 Irradiation and Etching the Samples

The experimental measurements of the present study were used to determine bulk etch rate (V_B) via measuring the thickness of removed layer for different detectors (CR-39) and for different alpha energies, and then applying the TRACK_TEST program and the following procedure has been depended.

The CR-39 detectors used in the present study were collected from four different companies Page Mouldings (Pershore) Limited (Worcestershire, England) and for different ages of the detectors (different in producing date). The detectors for our studies were cut to a size of 1 ×1 cm^2 with 0.1 cm (thickness).

Pieces of CR-39 detectors were irradiated with alpha particles with energies from 1 to 5MeV, with steps of 1MeV under normal incidence (see fig.2) through a collimator. The alpha source employed in the present study was a planar ^{226}Ra source (main α- energy = 5.49MeV under vacuum). Normal air was used as the energy absorber to control the final alpha energies incident on the detector . After irradiation, the detectors were etched in a 6 N aqueous solution of NaOH maintained at 70 C^o by a water bath for 4.5 hours of etching .The detectors were then taken out from the etchant, rinsed with distilled water and dried in air and the thickness removed layers were accounted in each steps of the etching.

4.2.2 Measurements

An optical microscope loaded with a calibrated foil eyepiece micrometer was used for measuring the alpha induced track diameter. Measurements were carried out under magnification of 12.5*X* (12.5 eye piece ×40 objectives) for a total scanned area of the detector equal to 76 $\times 10^{-4}$ cm^2.

5- Results and Discussion

The results were specified that the detectors older than 3 years seemed to show odd behaviors of V_B with detector efficiency. The trend is that V_B increases with decreasing age (see figure 3 and table 2). This behavior may be important in applications of this detector; for example, the calibration factor for radon measurements should be established by taking into account the age of the detector. Tables (3,4,5,6) shows the variation of track parameters with the bulk etch rate for different alpha particle energies (from 1 to 5 MeV) , in these tables we observed that V_B is not effective at high energies (from 4 to 5 MeV) , which means that one can use CR-39 detectors for calibration regardless of its age , but older detector cannot be used for application (fields of radon , thoron, …,etc.), because it can not be registered a correct density. So, the variations of detector characteristics with the age are important in this experiment. Detectors of different ages were etched in 6N NaOH solution at 70 C^o at 4.5h and V_B was determined to vary from (1.11) up to (3.11) µm/h. The variation of V_B was explained by the different ages of the various samples. The results show that all detectors had the same chemical composition, and they are differed only in additives, dopants, plasticizer and curing cycles. So the result shows that, the bulk etch rate, critical angle, and detector efficiency was similar for CR-39 detectors provided by different manufacturers. (See table 1). However, it should be noticed that the etch pit diameters themselves for alpha particles changed with bulk etch rate/ age as shown in Fig.4.The difference between the experiments of aging is very necessarily, because of the large uncertainty in the measurement of the sensitivity of solid state track detectors.

show odd behaviors of detector efficiency. For age=3years the efficiency decreases exponentially for different alpha particle energy, and for other ages, the relation shows odd behaviours.

In Figure 5 it should be noticed that the detectors older than 3 years seemed to It has been observed that the *V* values obtained in the present paper agree very well

with the results presented by Nikezica N. (2004), despite the different manufacturers of the CR-39 detectors.

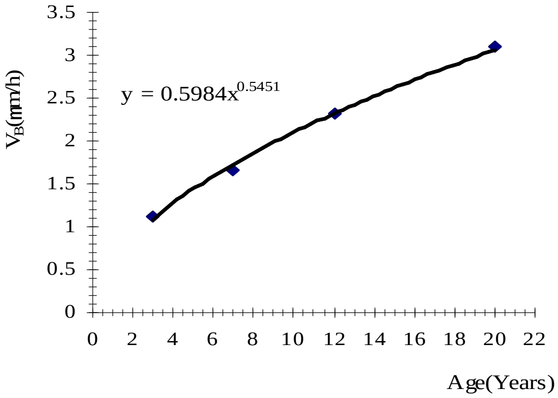

Fig. 3: Relation shape between age of

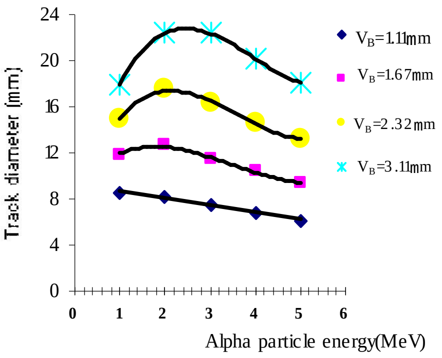

Fig. 4: Variation of Track diameter with the alpha particle energy for different V_B

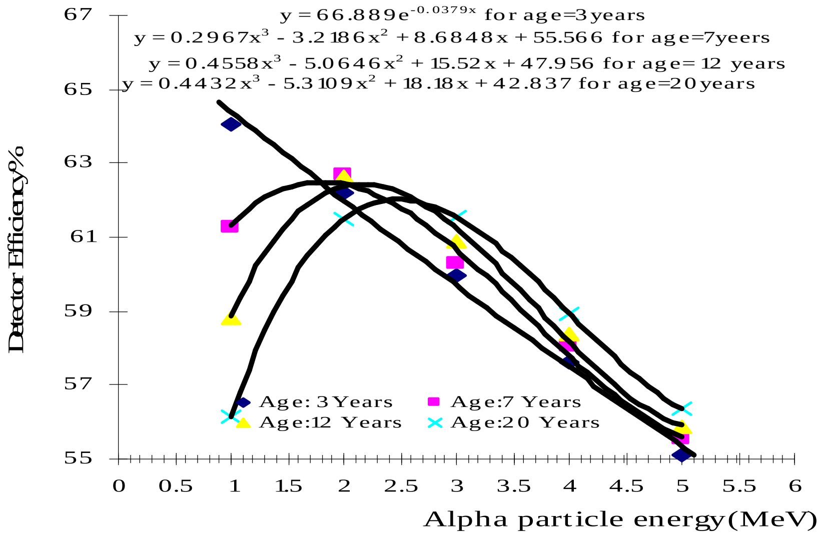

Fig.5: Relationships between detector efficiency and age of detector for different alpha particle energy.

Table (2): Calibration process of some important parameters for detection of 5.49MeV (2π Geometry) for different types of detectors (ages and companies).

Date Produced	**Age (years) To 2007**	**Company's Name**	**V_B (µm/h)**	**Track etch rate ratio $V=V_T/V_B$**	**Critical Angle(θc)**	**Efficiency *f* %**
CR-39(1987)	20	Mouldings (Pershore)	3.11±0.27	2.5684	22.913	61.066
CR-39(1995)	12	Mouldings (Pershore)	2.32±0.32	3.0269	19.2911	66.963
CR-39(2000)	7	Mouldings (Pershore)	1.67±0.08	2.3528	25.1522	57.497
CR-39(2003)	3	Mouldings (Pershore)	1.11±0.02	2.2059	26.956	54.66
CR-39(1995)	12	Intercast Europe Co. (Parma, Italy)	2.36±0.54	3.1429	18.5524	68.182
CR-39(1987)	20	Russian	3.011±0.4	2.62	22.4375	61.832
CR-39(2000)	7	Radaulab Norway	1.64±0.09	2.32991	24.6332	58.3189
CR-39(1996)	11	Fukuvi Chemical Industry Co., (Japan)	2.02±0.076	2.6188	22.4482	61.81

Table (3): Etching parameters for detection of alpha particle energies (1 - 5MeV) for V_B=1.11µm/h.

Alpha energy (MeV)	Track Diameter (µm)	Track etch rate ratio $V=V_T/V_B$	Critical Angle(θc)	Efficiency *f* %
1	8.54	2.709	21.662	63.08
2	8.2	2.6456	22.2089	62.201
3	7.48	2.497	23.608	59.95
4	6.79	2.359	25.081	57.609
5	6.13	2.227	26.681	55.09

Table (4): Etching parameters for detection of alpha particle energies (1 -5MeV) for V_B=1.67µm/h .

Alpha energy (MeV)	Track Diameter (µm)	Track etch rate ratio $V=V_T/V_B$	Critical Angle(θc)	Efficiency *f* %
1	11.89	2.582	22.78	61.27
2	12.62	2.679	21.917	62.67
3	11.425	2.52	23.379	60.31
4	10.4	2.383	24.81	58.03
5	9.398	2.25	26.387	55.55

Table (5): Etching parameters for detection of alpha particle energies (1 -5MeV) for V_B=2.32µm/h.

Alpha energy (MeV)	Track Diameter (µm)	Track etch rate ratio $V=V_T/V_B$	Critical Angle(θc)	Efficiency *f* %
1	14.91	2.428	24.321	58.81
2	17.49	2.675	21.952	62.61
3	16.27	2.558	23.012	60.90
4	14.66	2.404	24.58	58.4
5	13.22	2.266	26.187	55.86

Table (6): Etching parameters for detection of alpha particle energies (1 -5MeV) for V_B=3.11µm/h.

Alpha energy (MeV)	Track Diameter (µm)	Track etch rate ratio $V=V_T/V_B$	Critical Angle(θc)	Efficiency *f* %
1	17.9279	2.281	26.002	56.15
2	22.348	2.597	22.647	61.494
3	22.4	2.601	22.61	61.55
4	20.1	2.436	24.236	58.94
5	18.08	2.292	25.868	56.36

Conclusions

The age is not effected when CR-39 detectors has been used for calibration process, especially at high alpha particle energies. The track registration efficiency in CR-39 has been estimated and this detector has been found appreciably good for detection of low energy alpha particles. Etching characteristics, which have been studied in the present work, have good agreement with the results of other investigators in similar type of work (especially on new production). However, much more work is needed for investigation of different characteristics for the detection of alpha tracks in etched CR-39 detectors.

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پێوانەکردنی گۆشەی مۆڵەقە بۆ تۆمارکردنی ئاسەوار لە جەندین جۆری دۆزەرەوەی ئاسەواری ناوەکی رەق لە جۆریCR-39

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پوختە

50 نموونەی جۆرە دۆزەرەوەیەکی ناوەکی رەقمان لە جۆری(CR-39) بە ئەستورای و تەمنی جیاوازدا ئامادەکرد وە بۆ کۆمپانیای وەبەرهێنانیی جیاوازدا. پرۆگرامی (TRACK_TEST) بکارهات بۆ پێوانەکردنی زانراوەکانی ئاسەواری ناوەکی تۆمارکراو لە لایەن دۆزەرەوەی CR-3.

ئە نجامەکان دەری دەخەن کەوا هەستیاری وتوانای دۆزەوەرەکان پابەندیەکی بەهێزیان هەیە لە گەڵ کۆشەی مۆڵەقە(θc) بۆ تۆمارکردنی ئاسەواری ناوەکی , وە لە لایەکی تردا کۆشەی مۆڵەقە پابەندی بەهێزی هەیە لەگەڵ خێرای داتراشانی گشتی(V_B).

ئە نجامەکان ئەوە دەست نیشان دەکەن کەوا ئەو دۆزەرەوانەی کە تەمنیان لە 3 ساڵ زیاترە دیاردەی نامۆیان پێوە دیاردەکەوێت لە توانا و هەستیاریان دا . وە خێرایی داتراشانی گشتی(V_B) زیاد دەکات بە کەم بوونی تەمەنی دۆزەرەوەکان . ئەم چۆرە هەڵسوکەتانە زۆر گرنگە لە کاتی بەکارهێنانی ئەم دۆزەرەوانە , بۆ نموونە لە فاکتەری دەست نیشانکردنی پێوانەی گازی ڕادۆن دەبێ تەمەنی دۆزەرەوەکە هەژمار بکرێت و بە هەند وەربگیرێت .

قياس الزاوية الحرجة لتسجيل الآثار في مختلف كواشف الأثر النووي الصلب من نوعCR-39

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الخلاصة

هُيّأتْ 50 عينة بمختلف السمك والعمر من كاشفات الأثر النووي الصلب التجاري من نوع (CR-39) ومن شركات مختلفة .حسبت معاليم المسار النووي المسجل باستعمال ب حاسوب (TRAK_TEST)
وُجِدتْ في ال ئج أن كفاءة الكاشفِ تَعتمدَ بقوة على الزاويةِ الحرجةِ لإيحاءِ ا مسارِ **(θc)**.و من الناحية الأخرى، تَعتمدُ الزاويةَ الحرجةَ **(θc)**بقوة على سرعة تعفر و القشط العام (V_B).

حُدّدتْ النَتائِج بأنّ الكاشفاتَ الأقدم مِنْ 3 سَنَواتِ بَدتْ تظهر السلوكِ الشاذِّ في كفاءةِ الكاشفِ. ،وان سرعة القشط العام(V_B) تزداد بنَقْص العُمر. هذا السلوكِ قَدْ يَكُون مهمَ في تطبيقاتِ هذا الكاشفِ؛ على سبيل المثال، عامل التحديدَ لمقاييسِ غاز الرادون يَجِبُ أَنْ يؤخذ عمر الكاشف في الحسبان .

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